

Supplementary Information

Tree height and leaf drought tolerance traits shape growth responses across droughts in a temperate broadleaf forest

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Table S1. Monthly Palmer Drought Severity Index (PDSI), and its rank among all years between 1950 and 2009 (driest=1), for focal droughts.

year	month	PDSI	rank
1966	May	-2.98	2
	June	-3.40	2
	July	-4.08	2
	August	-4.82	1
1977	May	-2.96	3
	June	-3.28	3
	July	-3.61	3
	August	-3.68	3
1999	May	-3.63	1
	June	-4.21	1
	July	-4.53	1
	August	-4.64	2

Table S2. Species-specific bark thickness regression equations

Species	Equations	R^2
<i>Carya cordiformis</i>	$\ln[B] = -1.56 + 0.416 * \ln[DBH]$	0.226
<i>Carya glabra</i>	$\ln[B] = -0.393 + 0.268 * \ln[DBH]$	0.040
<i>Carya ovalis</i>	$\ln[B] = -2.18 + 0.651 * \ln[DBH]$	0.389
<i>Carya tomentosa</i>	$\ln[B] = -0.477 + 0.301 * \ln[DBH]$	0.297
<i>Fagus grandifolia</i>	$\ln[B] = 1 * \ln[DBH]$	
<i>Fraxinus americana</i>	$\ln[B] = 0.418 + 0.268 * \ln[DBH]$	0.256
<i>Juglans nigra</i>	$\ln[B] = 0.346 + 0.279 * \ln[DBH]$	0.246
<i>Liriodendron tulipifera</i>	$\ln[B] = -1.14 + 0.463 * \ln[DBH]$	0.545
<i>Quercus alba</i>	$\ln[B] = -2.09 + 0.637 * \ln[DBH]$	0.603
<i>Quercus prinus</i>	$\ln[B] = -1.31 + 0.528 * \ln[DBH]$	0.577
<i>Quercus rubra</i>	$\ln[B] = -0.593 + 0.292 * \ln[DBH]$	0.087

Table S3. Species-specific height regression equations

Species	Equations	X.R.2.
<i>Carya cordiformis</i>	$\ln[H] = 0.332+0.808*\ln[DBH]$	0.874
<i>Carya glabra</i>	$\ln[H] = 0.685+0.691*\ln[DBH]$	0.841
<i>Carya ovalis</i>	$\ln[H] = 0.533+0.741*\ln[DBH]$	0.924
<i>Carya tomentosa</i>	$\ln[H] = 0.726+0.713*\ln[DBH]$	0.897
<i>Fagus grandifolia</i>	$\ln[H] = 0.708+0.662*\ln[DBH]$	0.857
<i>Liriodendron tulipifera</i>	$\ln[H] = 1.33+0.52*\ln[DBH]$	0.771
<i>Quercus alba</i>	$\ln[H] = 0.74+0.645*\ln[DBH]$	0.719
<i>Quercus prinus</i>	$\ln[H] = 0.41+0.757*\ln[DBH]$	0.886
<i>Quercus rubra</i>	$\ln[H] = 1.00+0.574*\ln[DBH]$	0.755
all	$\ln[H] = 0.839+0.642*\ln[DBH]$	0.857

Table S4. Individual tests of species traits as drivers of drought resistance, where Rt is used as the response variable.

variable	category	all droughts		1966		1977		1999	
		$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients
xylem porosity	R	-0.80	0.0630	2.29**	0.190	1.92*	-0.152	3.36**	0.1500
	D/SR		0.0000		0.000		0.000		0.0000
<i>PLA</i>		6.70	-0.0140	9.13**	-0.025	-0.32	-0.010	-0.95	-0.0070
<i>LMA</i>		-2.01	0.0002	-1.9	0.001	-1.68	-0.002	-2.03	0.0003
π_{ulp}		1.33	-0.1740	-1.65	-0.107	1.23*	-0.245	-0.1	-0.1690
<i>WD</i>		-1.97	-0.0310	-1.26	-0.206	-1.44	-0.154	0.66	0.2720

Variable abbreviations are as in Table 2. $\Delta AICc$ is the $AICc$ of a model excluding the trait minus that of the model including it.

* $\Delta AICc > 1$: variable meets $\Delta AICc$ criterion for inclusion in full model

** $\Delta AICc > 2$: variable is considered significant as an individual predictor (and meets $\Delta AICc$ criterion for inclusion in full model)

Table S5. Individual tests of species traits as drivers of drought resistance, where Rt_{ARIMA} is used as the response variable.

variable	category	all droughts		1966		1977		1999	
		$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients	$\Delta AICc$	coefficients
xylem porosity	R	-1.47	0.0420	0.95	0.1520	2.84**	-0.171	2.27**	0.155
	D/SR		0.0000		0.0000		0.000		0.000
<i>PLA</i>		4.48**	-0.0120	10.15**	-0.0240	-0.9	-0.008	-1.67	-0.005
<i>LMA</i>		-1.99	-0.0003	-2.02	0.0005	-0.42	-0.003	-1.9	0.001
π_{tlp}		0.42	-0.1510	-1.94	-0.0530	-0.53	-0.179	0.04	-0.200
<i>WD</i>		-1.94	-0.0390	-0.08	-0.3040	-1.57	-0.142	0.83	0.316

Variable abbreviations are as in Table 2. $\Delta AICc$ is the $AICc$ of a model excluding the trait minus that of the model including it.

** $\Delta AICc > 2$: variable considered significant as an individual predictor

Table S6. Summary of top full models for each drought instance, where Rt is used as the response variable.

İ»¿drought	$\Delta AICc$	R^2	Intercept	$\ln[H]$	$\ln[TWI]$	$\ln[H] * \ln[TWI]$	PLA	π_{tlp}
all	0.000	0.12	1.131	-0.057	-0.086	-	-0.012	-0.113
	0.583	0.11	1.423	-0.055	-0.086	-	-0.013	-
	0.726	0.12	1.537	-0.202	-0.326	0.082	-0.012	-0.114
	1.352	0.11	1.826	-0.198	-0.324	0.081	-0.013	-
1966	0.000	0.25	1.622	-0.135	-	-	-0.025	-
1977	0.000	0.22	0.503	-	-0.144	-	-	-0.24
	0.908	0.21	1.069	-	-0.144	-	-	-
	0.988	0.22	0.568	-0.03	-0.139	-	-	-0.246
	1.144	0.24	0.684	-	-0.142	-	-0.007	-0.204
	1.267	0.22	1.211	-	-0.141	-	-0.01	-
1999	0.000	0.18	1.061	-	-0.102	-	-	-
	0.023	0.19	0.659	-	-0.101	-	-	-0.169
	0.954	0.19	1.157	-	-0.1	-	-0.007	-
	1.513	0.21	0.783	-	-0.1	-	-0.005	-0.145
	1.803	0.18	1.024	0.013	-0.103	-	-	-
	1.901	0.19	0.635	0.011	-0.102	-	-	-0.166

Models are ranked by AICc. Shown are all models whose AICc value falls within 2.0 ($\Delta AICc < 1$) of the best model (bold). R^2 refers to conditional R^2 . Year was included in the model for all drought years, but its effect was not included in any top models, and coefficients were small (1966: 0, 1977: -0.019, 1999: -0.005; same values in all top models).

Table S7. Summary of top models for each drought instance, where Rt_{ARIMA} is used as the response variable.

$\ddot{\mathbf{i}}_{\mathbf{j}} \text{drought}$	ΔAICc	R^2	Intercept	$\ln[H]$	$\ln[TWI]$	$\ln[H] * \ln[TWI]$	PLA	π_{ulp}	$(1 sp)[no\text{variables}]$
all	0.000	0.09	1.125	-0.307	-0.506	0.140	-0.012		
	0.425	0.10	0.879	-0.310	-0.508	0.140	-0.011	-0.096	
	1.208	0.09	0.424	-0.060	-0.100		-0.012		
	1.695	0.10	0.178	-0.061	-0.100		-0.011	-0.095	
1966	0.000	0.23	1.660	-0.154			-0.024		
	1.393	0.23	1.735	-0.152	-0.047		-0.024		
	1.457	0.23	1.859	-0.152			-0.025	0.078	
1977	0.000	0.16	1.130		-0.180				
	0.424	0.16	2.453	-0.461	-0.896	0.250			
	0.688	0.17	0.720		-0.179			-0.173	
	0.922	0.17	2.040	-0.466	-0.898	0.251		-0.180	
	0.927	0.17	1.248		-0.177		-0.008		
	1.322	0.17	2.569	-0.461	-0.893	0.250	-0.008		
	1.709	0.15	1.183	-0.020	-0.177				
1999	0.000	0.20	0.563		-0.076			-0.200	
	0.064	0.19	0.421					-0.202	
	0.127	0.18	1.036		-0.077				
	0.256	0.18							0.899
	1.777	0.20	0.529	0.016	-0.078			-0.195	
	1.797	0.20	1.101		-0.076		-0.004		
	1.815	0.18	0.986	0.018	-0.079				
	1.838	0.20	0.972				-0.005		
	1.933	0.19	0.391	0.012				-0.199	
	1.979	0.21	0.612		-0.075		-0.002	-0.190	
	1.999	0.21	0.482				-0.002	-0.190	

Models are ranked by AICc. Shown are all models whose AICc value falls within 2.0 ($\Delta\text{AICc} < 1$) of the best model (bold). R^2 refers to conditional R^2 . Year was included in the model for all drought years, but its effect was not included in any top models, and coefficients were small (1966: 0, 1977: -0.03, 1999: 0.008; same values in all top models).



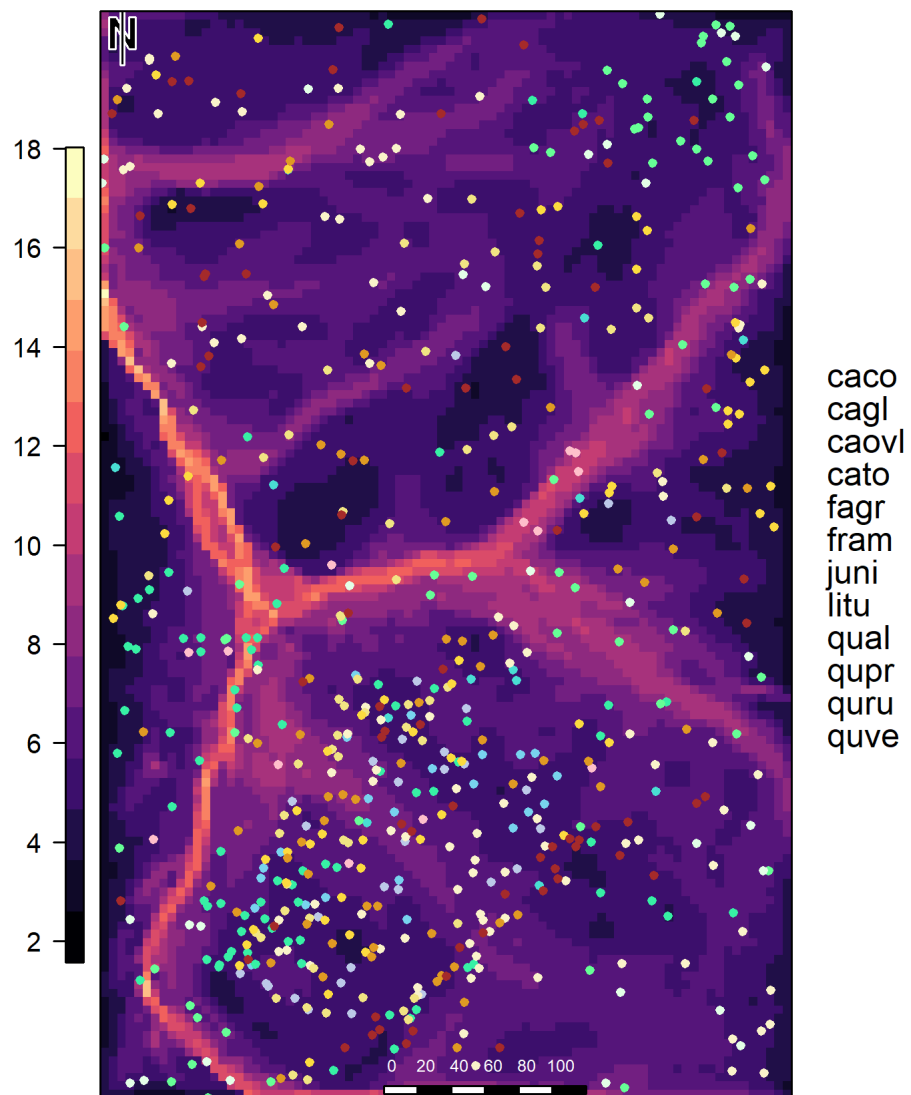


Figure S2. Map of ForestGEO plot showing topographic wetness index and location of cored trees

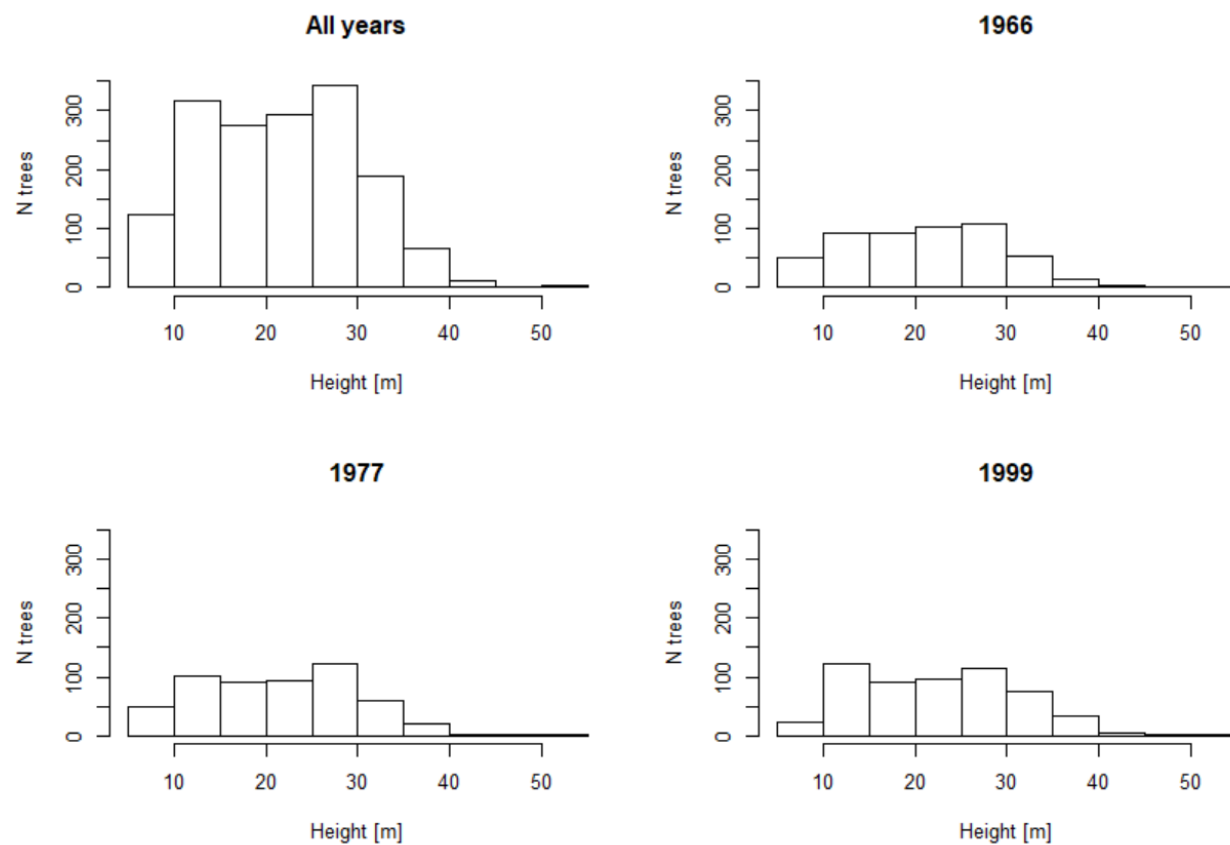


Figure S3. Distribution of reconstructed tree heights across drought years.

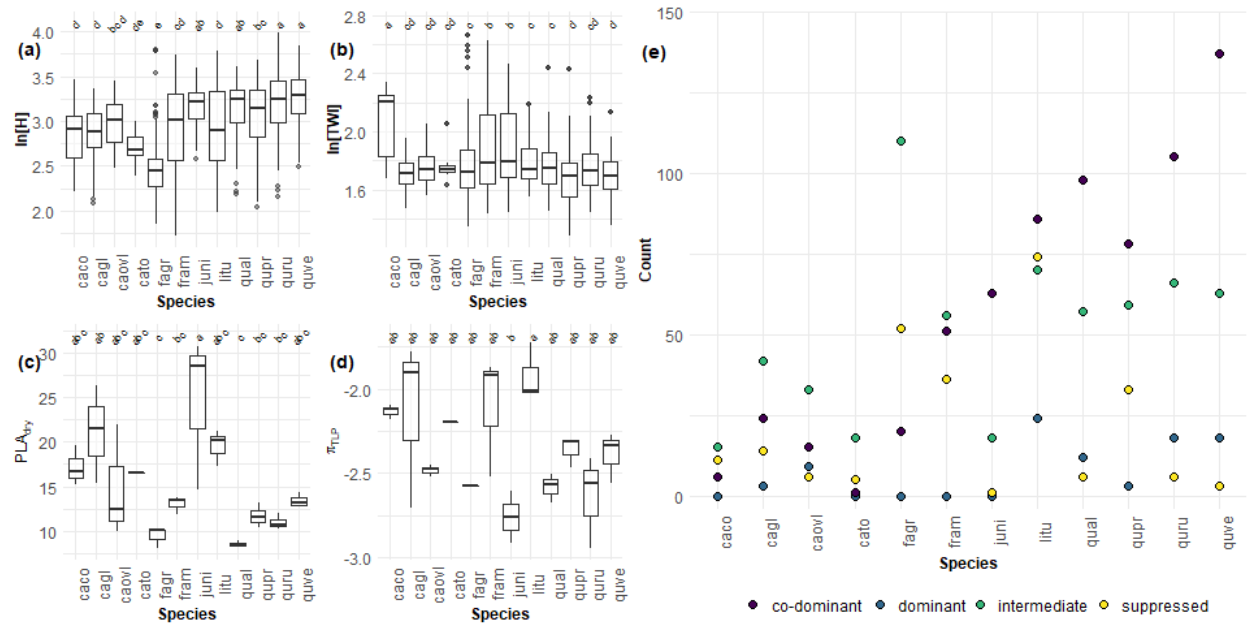


Figure S4. Distribution of independent variables by species. Species that are assigned the same letter are not significantly different from each other with regard to the tested variable.

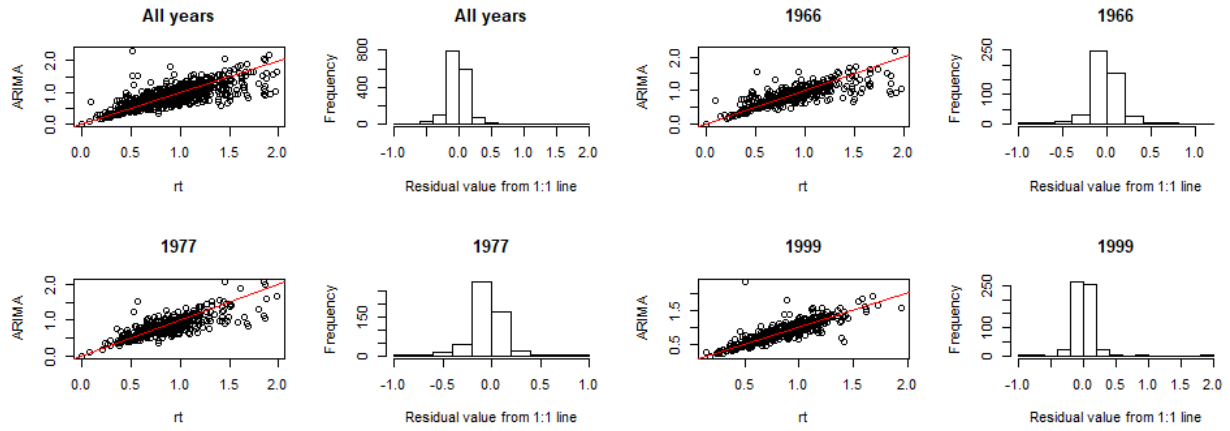


Figure S5. Comparison of R_t and R_{tARIMA} results, with residuals, for each drought scenario

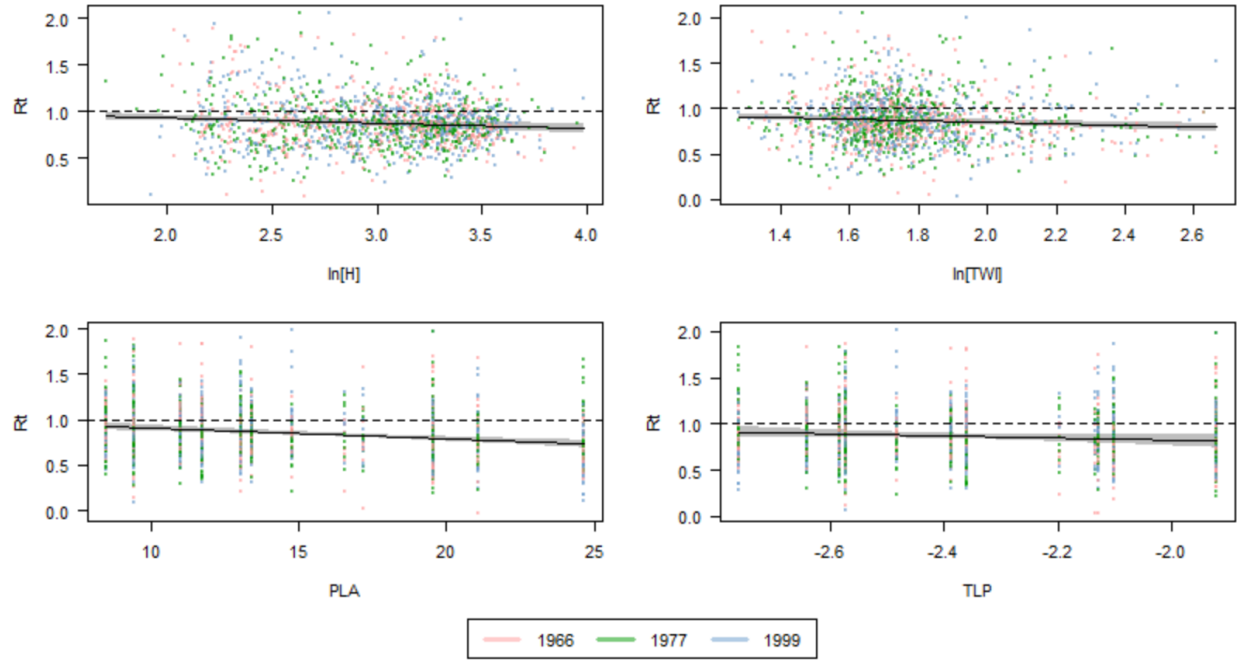


Figure S6. Visualization of best model, with data, for all droughts combined. Model coefficients are given in Table S6.

Further Package Citations

While there were several R-packages we used for a specific purpose in our methods, numerous packages were immensely helpful for this research behind the scenes. As in all of science, this study is a representation of the work done by both the authors of this paper as well as countless others. While acknowledging everyone is impossible, we want to at least give thanks to those who made this work possible.

R-packages not already cited in the main manuscript include the following, listed alphabetically by corresponding package name:

(Urbanek, 2013; Winston Chang, 2014; Augue, 2017; Wickham, 2017, 2019; Spinu *et al.*, 2018; Arnold, 2019; Barton, 2019; Bivand *et al.*, 2019; Bivand & Rundel, 2019; Bunn *et al.*, 2019; Dowle & Srinivasan, 2019; Fox *et al.*, 2019; Henry & Wickham, 2019; Lefcheck *et al.*, 2019; Perpinan Lamigueiro & Hijmans, 2019; R Core Team, 2019; Wickham & Bryan, 2019; Wickham *et al.*, 2019, 2020a,b; Wilke, 2019; Allaire *et al.*, 2020; Gagolewski *et al.*, 2020; Hijmans, 2020; Kassambara, 2020; Pebesma, 2020; Robinson & Hayes, 2020; Temple Lang, 2020; Wickham & Henry, 2020; Xie, 2020)

Allaire J, Xie Y, McPherson J, Luraschi J, Ushey K, Atkins A, Wickham H, Cheng J, Chang W, Iannone R. **2020**. *Rmarkdown: Dynamic documents for r*.

Arnold JB. **2019**. *Ggthemes: Extra themes, scales and geoms for 'ggplot2'*.

Augue B. **2017**. *GridExtra: Miscellaneous functions for "grid" graphics*.

Barton K. **2019**. *MuMIn: Multi-model inference*.

Bivand R, Keitt T, Rowlingson B. **2019**. *Rgdal: Bindings for the 'geospatial' data abstraction library*.

Bivand R, Rundel C. **2019**. *Rgeos: Interface to geometry engine - open source ('geos')*.

Bunn A, Korpela M, Biondi F, Campelo F, Mérian P, Qeadan F, Zang C. **2019**. *DplR: Dendrochronology program library in r*.

Dowle M, Srinivasan A. **2019**. *Data.table: Extension of 'data.frame'*.

Fox J, Weisberg S, Price B. **2019**. *Car: Companion to applied regression*.

Gagolewski M, Tartanus B, IBM, Unicode, Inc., Unicode, Inc. **2020**. *Stringi: Character string processing facilities*.

Henry L, Wickham H. **2019**. *Purrr: Functional programming tools*.

Hijmans RJ. **2020**. *Raster: Geographic data analysis and modeling*.

Kassambara A. **2020**. *Ggpubr: 'Ggplot2' based publication ready plots*.

Lefcheck J, Byrnes J, Grace J. **2019**. *PiecewiseSEM: Piecewise structural equation modeling*.

Pebesma E. **2020**. *Sf: Simple features for r*.

Perpinan Lamigueiro O, Hijmans R. **2019**. *RasterVis: Visualization methods for raster data*.

R Core Team. **2019**. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Robinson D, Hayes A. **2020**. *Broom: Convert statistical analysis objects into tidy tibbles*.

Spinu V, Grolemund G, Wickham H. **2018**. *Lubridate: Make dealing with dates a little easier*.

Temple Lang D. **2020**. *RCurl: General network (http/ftp/...) client interface for r*.

Urbanek S. **2013**. *Png: Read and write png images*.

Wickham H. **2017**. *Reshape2: Flexibly reshape data: A reboot of the reshape package*.

Wickham H. **2019**. *Stringr: Simple, consistent wrappers for common string operations*.

Wickham H, Bryan J. **2019**. *Readxl: Read excel files*.

Wickham H, Chang W, Henry L, Pedersen TL, Takahashi K, Wilke C, Woo K, Yutani H. **2019**. *Ggplot2: Create elegant data visualisations using the grammar of graphics*.

Wickham H, François R, Henry L, Müller K. **2020a**. *Dplyr: A grammar of data manipulation*.

Wickham H, Henry L. **2020**. *Tidyr: Tidy messy data*.

Wickham H, Hester J, Chang W. **2020b**. *Devtools: Tools to make developing r packages easier*.

Wilke CO. **2019**. *Cowplot: Streamlined plot theme and plot annotations for 'ggplot2'*.

Winston Chang. **2014**. *Extrafont: Tools for using fonts*.

Xie Y. **2020**. *Knitr: A general-purpose package for dynamic report generation in r*.